PEDESTRIAN TRAVEL-TIME MAPS FOR CORDOVA, ALASKA: An anisotropic model to support tsunami evacuation planning

by

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ABSTRACT

Tsunami-induced pedestrian evacuation for Cordova is evaluated using an anisotropic modeling approach developed by the U.S. Geological Survey. The method is based on path-distance algorithms and accounts for variations in land cover and directionality in the slope of terrain. We model evacuation of pedestrians to exit points from the tsunami hazard zone. The pedestrian travel is restricted to the roads only. Results presented here are intended to provide guidance to local emergency management agencies for tsunami inundation assessment, evacuation planning, and public education to mitigate future tsunami hazards.

The Cordova Waterfront and small boat harbor. Photo by Rich D. Koehler.

INTRODUCTION

Subduction of the Pacific plate under the North American plate has resulted in numerous great earthquakes and has the highest potential to generate tsunamis in Alaska (Dunbar and Weaver, 2015). The Alaska–Aleutian subduction zone (figure 1), the fault formed by the Pacific–North American plate interface, is the most seismically active tsunamigenic fault zone in the U.S. Refer to Nicolsky and others (2014) for an overview of the tsunami hazard in the Cordova area.

The most recent earthquake that triggered a significant tsunami in Cordova occurred on March 27, 1964; for this event, tsunami waves were as high as 7.6 m (25 ft) (Lander, 1996). The tsunami caused damage to some coastal facilities and a drowning at a small fishing camp southwest of Cordova (Wilson and Tørum, 1972, and Plafker and others, 1969). An in-depth analysis of the tsunami hazard in Cordova and estimation of the tsunami hazard zone in the community is provided by Nicolsky and others (2014).

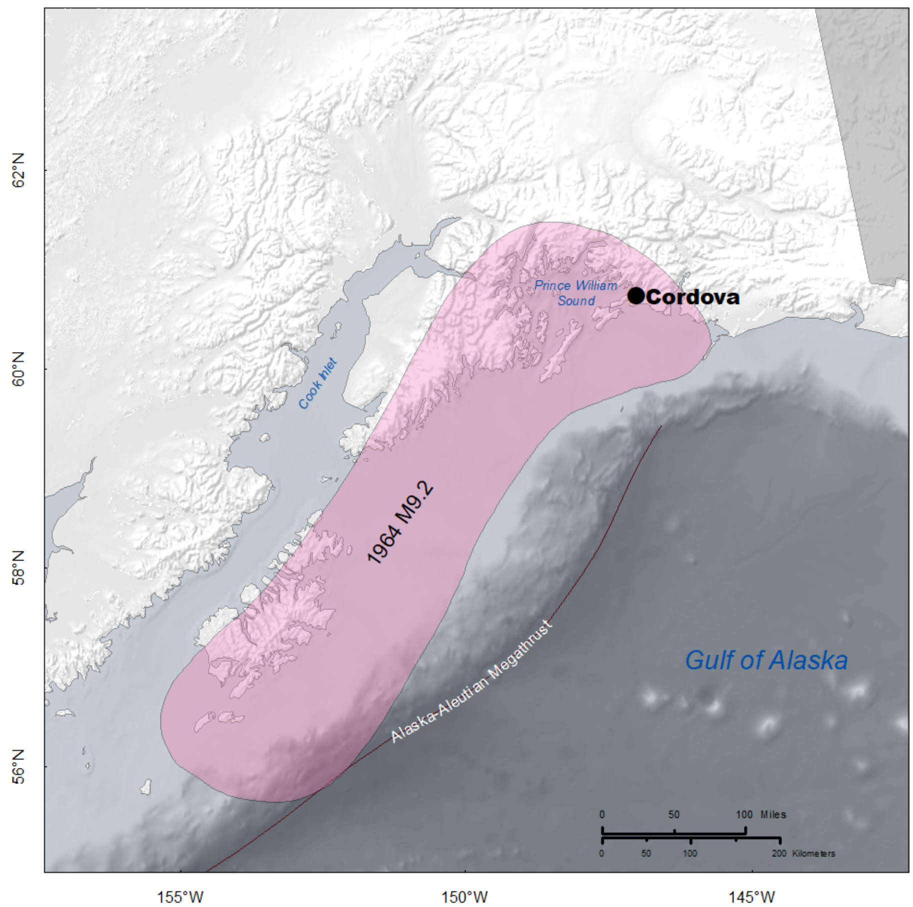

Figure 1: Map of south-central Alaska, showing the location of Cordova and the rupture zone of the 1964 Aleutian subduction zone earthquake (shaded area).

In this report, we employ the pedestrian evacuation modeling tools developed by the U.S. Geological Survey (USGS) (Wood and Schmidtlein, 2012, 2013; Jones and others, 2014) to provide guidance to emergency managers and community planners in assessing the amount of time required for people to evacuate out of the tsunami-hazard zone. An overview of the pedestrian evacuation modeling tools, required datasets, and the step-by-step procedure used is provided in Macpherson and others (2017, this series). The maps of pedestrian travel time can help identify areas in Cordova on which to focus evacuation training and tsunami education.

COMMUNITY PROFILE

The city of Cordova (60°32’N, 145°45’W) was founded in March 1906, near the Alaska Native Village of Eyak, at the base of Mount Eyak. The city is roughly 52 mi (83km) southeast of Valdez and 150 mi (240 km) southeast of Anchorage. In its early years, Cordova was a terminus for the Copper River and Northwestern Railroad. Today, Cordova is a fishing and canning center for the Prince William Sound Region. The Cordova harbor is a port for the Alaska Marine Highway System and has ferry service year-round. According to the 2010 census, the city population is 2,289.

The 1964 earthquake caused widespread damage to infrastructure outside the city of Cordova, however the ensuing tsunami caused the majority of damage to the city itself. According to reports, six tsunami waves struck the harbor. The highest wave coincided with the highest tide and was reported to reach 20 ft above Mean Lower Low Water (MLLW) and flooded up to 300 ft inland. See Nicolsky and others, 2014 for more on the 1964 tsunami impact.

TSUNAMI HAZARD

Tsunami hazard assessment for Cordova was performed by numerically modeling several hypothetical scenarios (Nicolsky and others, 2014). The worst-case scenarios for Cordova are thought to be thrust earthquakes beneath Prince William Sound with magnitudes above M_w 8.8.

Nicolsky and others (2014) estimate that the tsunami wave could be around 6 m (18 ft) high and would arrive approximately 45 - 60 minutes after the earthquake. Modeled extents of the potential inundation in the Cordova harbor area computed by Nicolsky and others (2014) is shown by the red line in figure 2.

The hydrodynamic model used to calculate propagation and runup of tsunami (Nicolsky and others, 2011) has passed the appropriate validation and verification tests (Synolakis and others, 2007; NTHMP, 2012). We emphasize that although the developed algorithm has met the benchmarking procedures, there is still uncertainty in locating an inundation line. For example, the accuracy is affected by many factors on which the model is based, including suitability of the earthquake source model, accuracy of the bathymetric and topographic data, and the adequacy of the numerical model in representing the

Figure 2: Map of Cordova boat harbor and ferry terminal depicting modeled extent of the potential inundation (red line) and the tsunami hazard zone, based on the 10% increase in the tsunami runup (blue line).

generation, propagation, and runup of tsunamis. We refer to Nicolsky and others (2014) for further in-depth discussion of the uncertainty in the modeled tsunami hazard zone.

Figure 3: Map of the harbor area depicting the modeled extent of the potential inundation (red line) and the suggested assembly zone (light green).

To account for the above-mentioned uncertainties, we enlarge the modeled extent of potential inundation by adding a safety buffer, see Figure 2. In particular, areas within 45 m (150 ft) of the inundation line and with the elevations less than 110% of the local runup are thought to be a risk of flooding in the worst-case tsunami event. The potential inundation extent together with the safety buffer is to be called the tsunami hazard zone.

Following consultation with the city Emergency Management Coordinators after the presentation of the preliminary modeling results (October 16, 2019), it was decided to enlarge the tsunami hazard zone in order it to extend to 1st St. and then along Lake Ave., see Figure 3 (see also Map Sheet 1 for a large copy). Areas above 1st St. and Lake Ave. can serve as an assembly area and shelter-in-place zone[1] in case of tsunamis.

The designated assembly zone is was then used for the pedestrian travel time modeling in the harbor area, while the original safety buffer line (Map Sheet 2) is used along Whitshed Rd. in the south.

PEDESTRIAN EVACUATION MODELING

Pedestrian evacuation modeling and prediction of population vulnerability to tsunami hazards were successfully applied to coastal communities in Alaska by Wood and Peters (2015). Also refer to Wood and Schmidtlein (2012, 2013) for an overview and limitations of the anisotropic, least-cost distance (LCD) approach to modeling pedestrian evacuation. We stress that the LCD focuses on the evacuation landscape, using characteristics such as elevation, slope, and land cover to calculate the most efficient path to safety.

[1] It should be noted that no final decision to draw the shelter-in place zone along the 1st St and Lake Ave. was taken at the October 2019 meeting. Always consult with the local emergency coordinators regarding the city-adopted tsunami evacuation and shelter-in-place lines.

Therefore, computed travel times are based on optimal routes, and actual travel times may be greater depending on individual route choice and environmental conditions during an evacuation.

Recently, Jones and others (2014) developed the Pedestrian Evacuation Analyst Extension (PEAE) for ArcGIS, which facilitates development of pedestrian travel-time maps. A brief overview of the PEAE and a step-by-step procedure to compute the pedestrian travel-time maps for Alaska coastal communities are provided in Macpherson and others (2017, this series). Note that the data required for the PEAE include: either the tsunami hazard zone or exit points, digital elevation model (DEM) of the community, and land-cover datasets. In the following sections we describe datasets required to compute the travel-time maps, considered scenarios, and modeling results.

DATA COMPILATION AND SOURCES

The following section details the datasets that were obtained and/or created for the community to be used as input for the PEAE. In all cases we used the maximum composite tsunami hazard zone instead of a specific tectonic scenario. All datasets and layers were projected to NAD83 Alaska State Plane Zone 3 m to allow us to compute the final evacuation times in minutes. The original sources of data are summarized in Table 1.

- **Exit points:** Exit points are continuously located on the boundary of the assembly area in the harbor area (see a green bright line in Figure 3 or Map Sheet 1) and at some locations along Whitshed Rd. (see green rectangles in Map Sheet 2).
- **Digital Elevation Model:** The DEM employed in this study is consistent with the tsunami DEM used by Nicolsky and others (2014) to compute the tsunami inundation. The original source for topographic elevations is the National Geophysical Data Center (NOAA), with a spatial resolution of about 13 × 16 m (44 x 54 ft). Note that the tsunami DEM was re-sampled using the PEAE tool to set the analysis cell size at 3 m (10 ft) resolution to improve the accuracy of the travel-time maps.
- **Land Cover:** Roads and trails were added from the OpenStreetMap API (OSM, 2015) and confirmed using high-resolution imagery from the Digital Globe Imagery provided by ESRI. Only the constructed and well-maintained roads are used in the computations.

Table 1. Data sources of the input layers required for the Pedestrian Evacuation Analyst Extension.

Layer in PEAE	Data Sources
Tsunami Inundation Extent	Nicolsky and others (2014)
Exit points	Located on the roads leading from the buffered inundation extent. Locations of the exit points are chosen together with the community members
DEM	Caldwell and others (2009)
Land Cover	Digital Globe imagery
Roads	OpenStreetMap, expanded using Digital Globe Imagery
Imagery	Digital Globe imagery

EVACUATION SCENARIOS

Unlike previous reports, where we consider multiple scenarios involving evacuation by roads and/or across all possible terrain. In Cordova, extreme snow precipitation events can severely restrict walking off snow-cleared roads. We therefore assume that pedestrians will travel to the closest road and then stay on roads to leave the tsunami hazard zone. In this report, we thus model the pedestrian evacuation time only for a single scenario[2] - **Evacuation to the nearest exit point by roads only**.

We emphasize that the assumed base speed of the evacuee is set according to the "slow walk" option (0.91 m/s, 3 ft/s, or 2 mph) in the PEAE settings. Note that this is a conservative speed and many residents would be able to evacuate faster (1.52m/s "fast walk", if not 1.79m/s "slow run") than the modeled rate. However, soil liquefaction, darkness, freezing rain, ice and/or snow on the road can also significantly impact the walking pace of evacuees.

We also assume that individuals travel to the nearest exit point in the most optimal way. The latter requires tsunami evacuation signage along the roads.

MODELING RESULTS

We apply the methodology outlined in Macpherson and others (2017, this series) to compute the travel times according to the considered scenario. The pedestrian travel-time map for the harbor area is shown in Figure 4 (see also Map Sheet 3 for a larger copy).

Modeled pedestrian travel times to exit points (shown by green squares or the assembly zone boundary) can reach upwards of 25 minutes for evacuees at the Ferry Terminal and can exceed 30 minutes for evacuees on New England Canery Rd., north of the terminal. These estimates do not include any milling time or additional extras needed to deboard the ferry. Clear tsunami evacuation signs and direction could be used to guide the public out of the hazard zone.

The modeling results for the areas south of the harbor (Figure 5 or Map Sheet 4) show that areas along Whitshed Rd., south of Three Mile Bay, would require evacuees to travel upwards of 30 minutes to reach the nearest exit point.

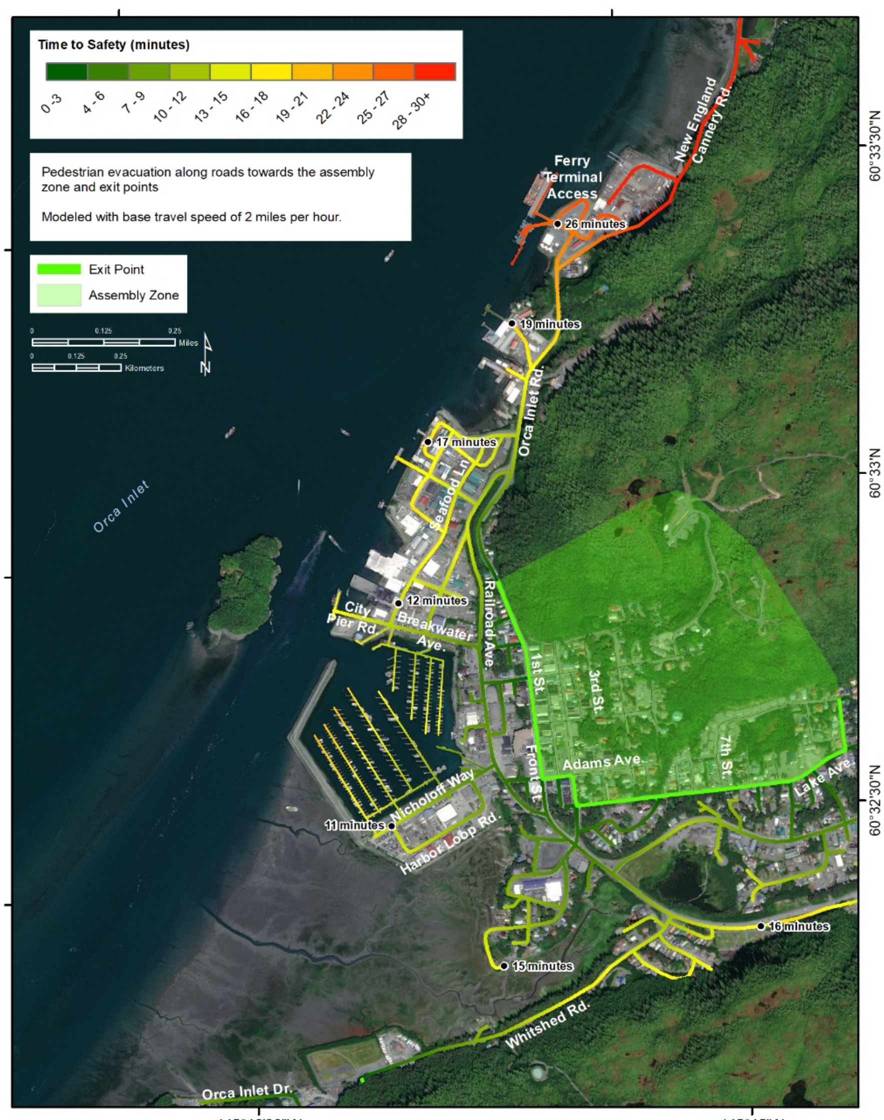

Figure 4: Travel time maps for the pedestrian evacuation for the Cordova harbor area. Pedestrians exit the tsunami hazard zone after reaching certain locations colored by light green on 1st St. and Lave Ave. Color gradation indicates how many minutes it would take for an evacuee to walk to the nearest exit point.

[2] Additional scenarios could be considered and added based on the community feedback.

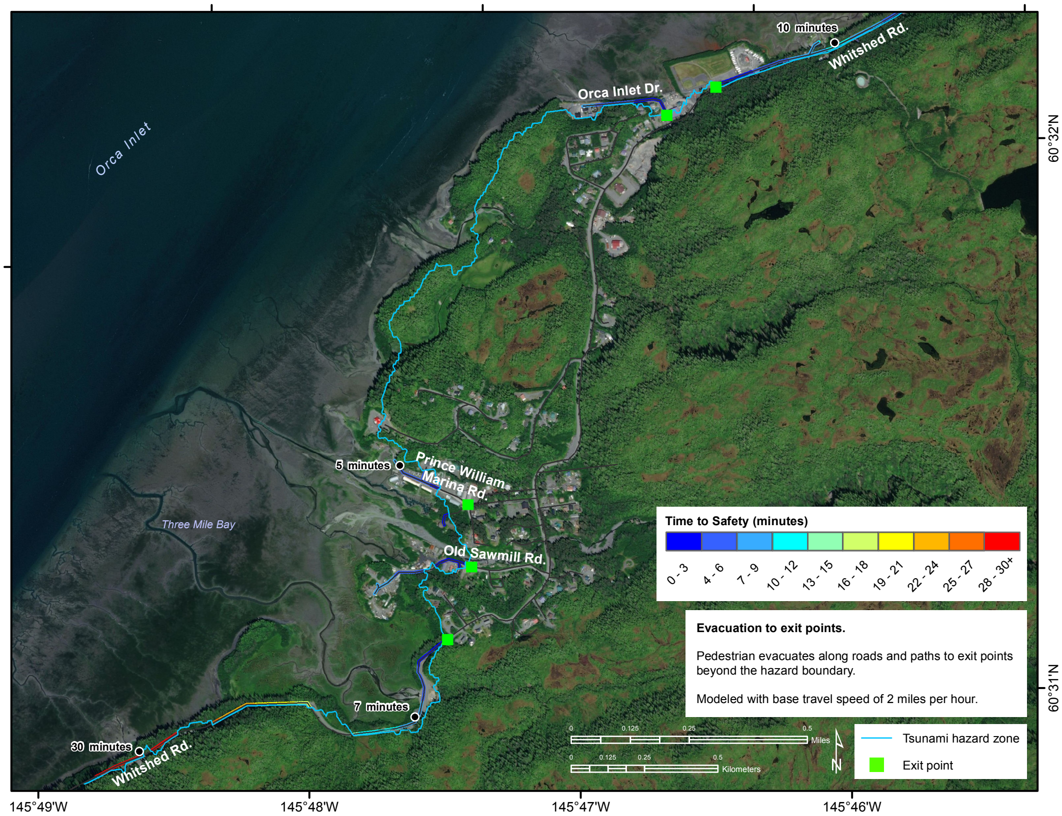

Figure 5: Travel time maps for the pedestrian evacuation for southern Cordova around Three Mile Bay. Exit points are marked by the green rectangles, the tsunami hazard zone is shown by the blue line. Color gradation indicates how many minutes it would take for an evacuee to walk to the nearest exit point.

The modeling results for eastern part of the city (Figure 6a, also Map Sheet 5) show that areas along the lake shore would require evacuees to travel upwards of 30 minutes to reach the assembly zone at Lake Ave. However, if two auxiliary exit points are added on both sides of the shore, then the walking time could be cut in half (Figure 6b, also Map Sheet 6).

Figure 6: Travel time maps for the pedestrian evacuation for eastern part of Cordova around Eyak Lake. (A) Evacuation to the assembly area along Lake Ave. (B) Evacuation both to the assembly area and two exit points on both sides of the lake. Exit points are marked by the green rectangles. Color gradation indicates how many minutes it would take for an evacuee to walk to the nearest exit point.

SOURCES OF ERRORS AND UNCERTAINTIES

The modeling approach described in this report will not exactly represent an actual evacuation; like all evacuation models, the LCD approach cannot fully capture all aspects of individual behavior and mobility (Wood and Schmidtlein, 2012). The weather conditions, severe shaking, soil liquefaction, infrastructure collapse, downed electrical wires, and the interaction of individuals during the evacuation will all influence evacuee movement. Refer to Wood and Schmidtlein (2012, 2013), Jones and others (2014), and Macpherson and others (2017, this series) for an in-depth discussion of the limitations of the LCD approach in estimating the travel times to safety.

SUMMARY

Pedestrian travel times to the nearest exit point from the tsunami hazard zone are typically less than 20 minutes, which is well less than an estimated travel time of the hypothetical tsunami from the Gulf of Alaska to the city waterfront. Successful evacuation seems feasible given clear evacuation road signage and educational efforts to inform the public about the optimal routes to safety. At the same time, Cordova like many other Alaska coastal communities is built between the mountains and ocean. Hence, there is a long stretch of New England Cannery Rd. in the tsunami hazard zone, evacuation from which may be challenging since it would take a considerable amount of time for evacuees to reach their nearest exit point from the tsunami hazard zone. Evacuation onto the mountain slope is not considered, because of the steep terrain and absence of emergency services. Potential rock falls and snow avalanches could be triggered by aftershocks leading to secondary causalities. Individuals along some parts of New England Cannery Rd. need to walk faster than 2mph or seek alternative evacuation routes (e.g. trails) in order to reach safety before the first wave arrives.

Maps accompanying this report have been completed using the best information available and are believed to be accurate; however, the report's preparation required many assumptions. In most cases the actual walking speeds proved faster than those modeled. The information presented on these maps is intended to assist state and local agencies in planning emergency evacuation and tsunami response actions. These results are not intended for land-use regulation or building-code development.

ACKNOWLEDGMENTS

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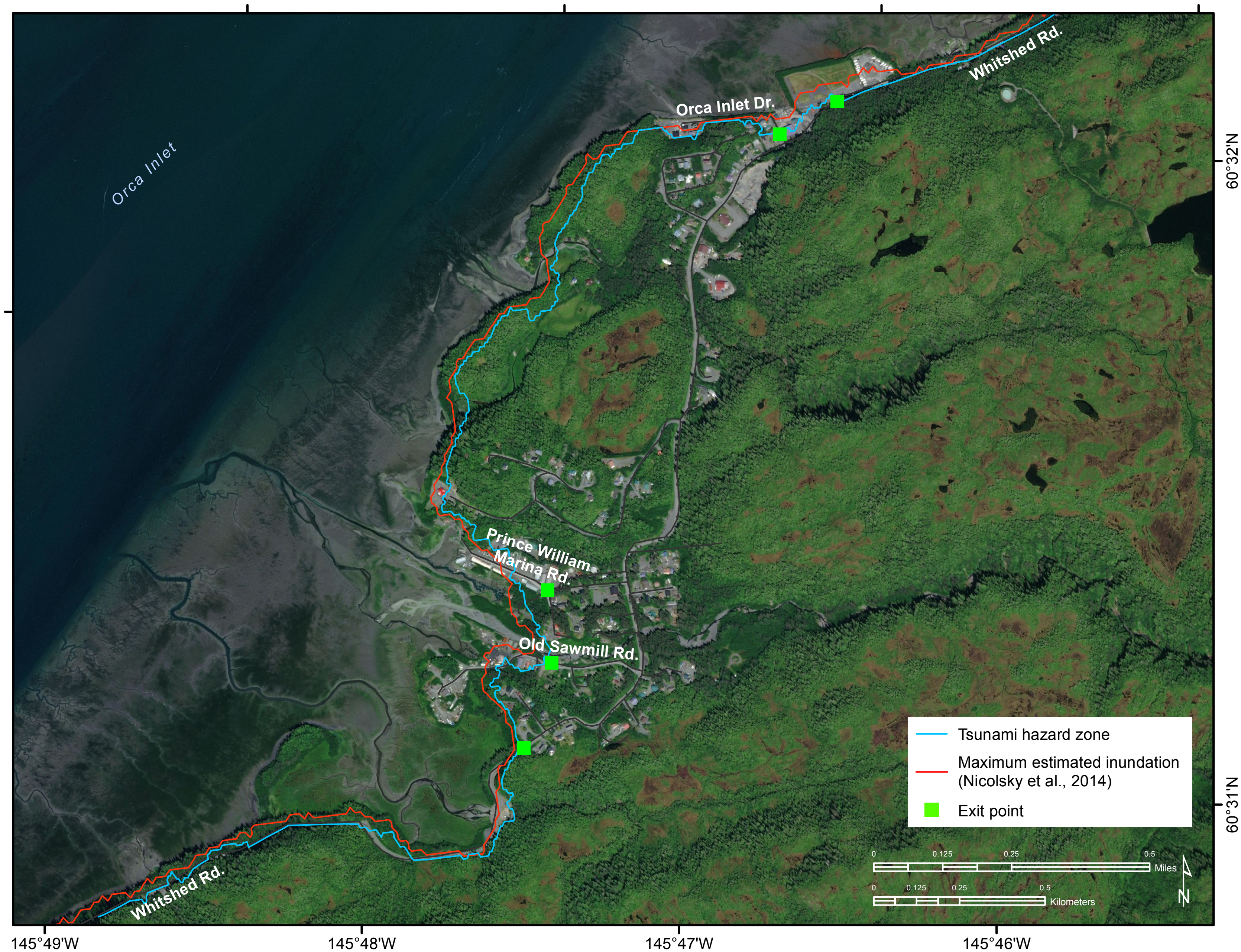
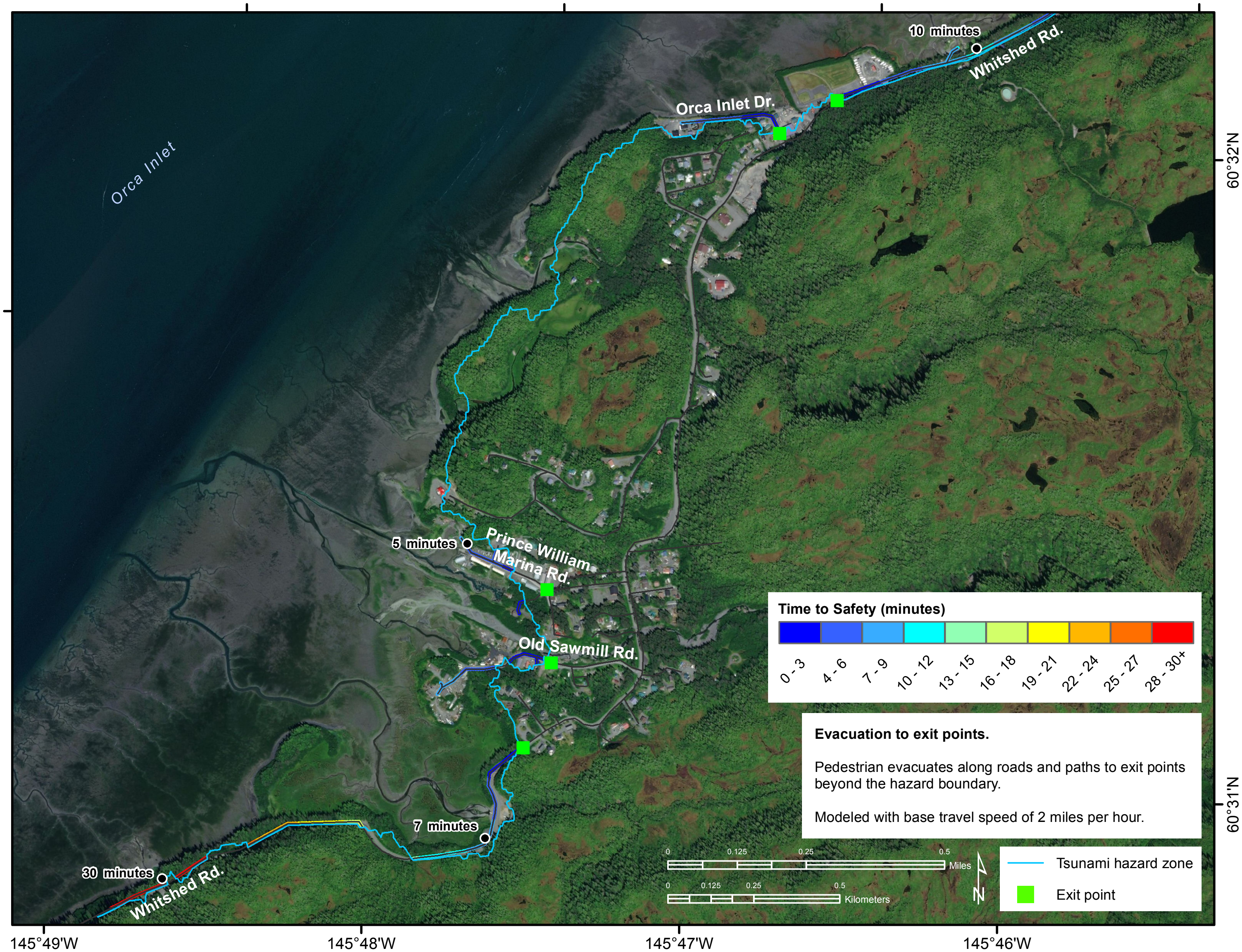
MAP SHEET 1: Modeled extent of the potential inundation and designed assembly zone*.

*Always consult with current city regulations regarding the tsunami shelter-in-place zone.

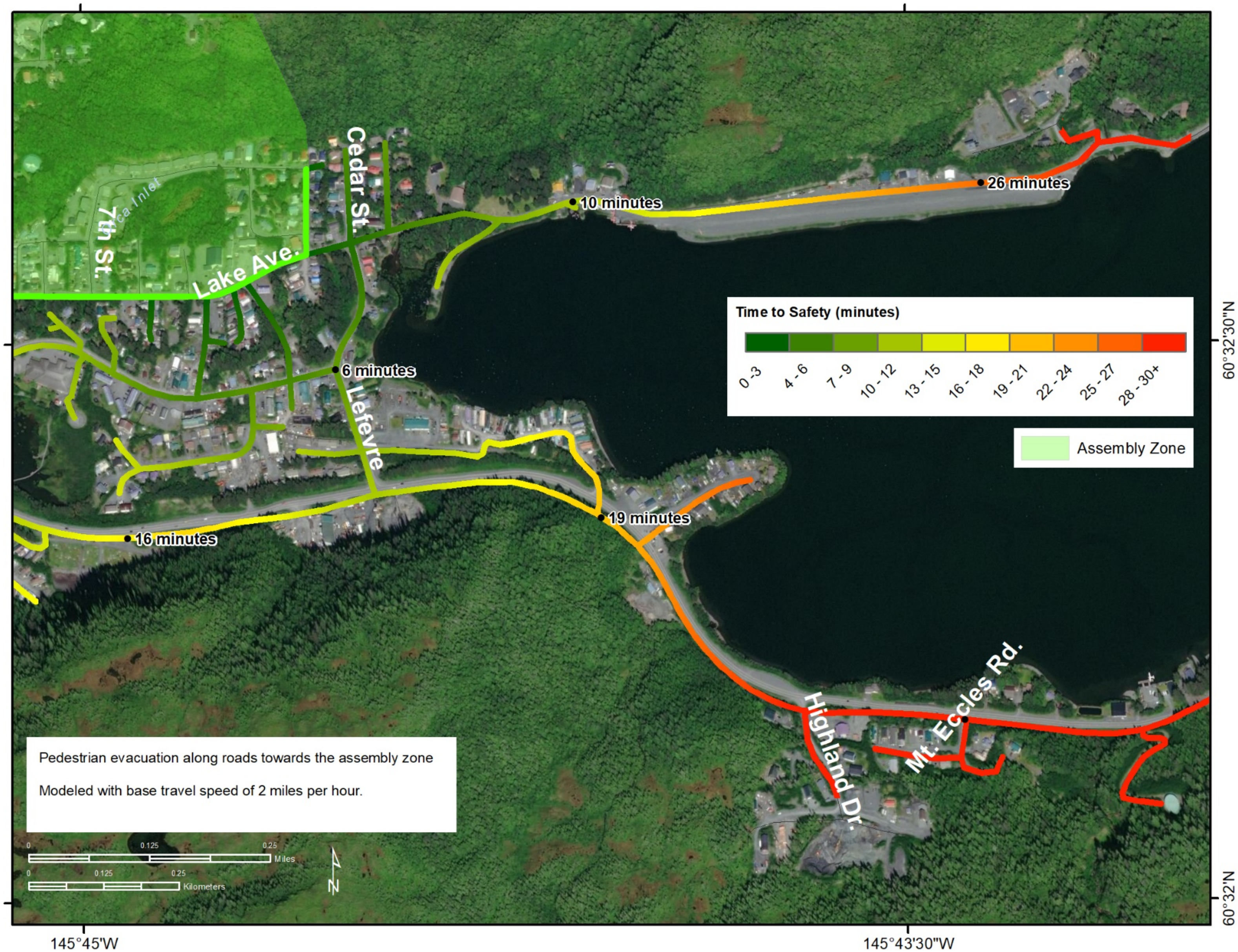


MAP SHEET 2: Modeled extent of the potential inundation and estimated tsunami hazard zone along Whitshed Rd.

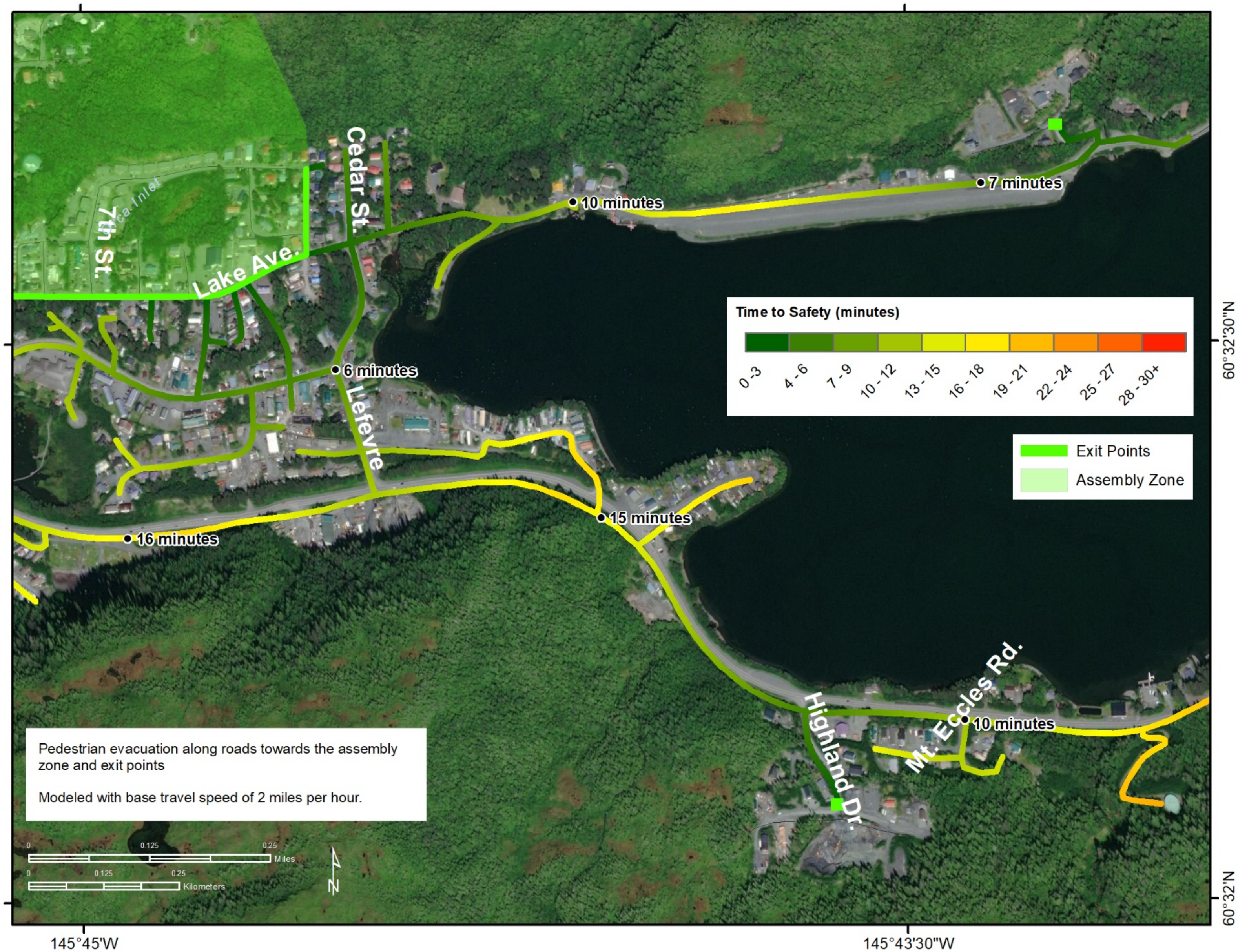
MAP SHEET 3: Travel-time map of pedestrian evacuation to the designed assembly zone.



MAP SHEET 4: Travel-time map of pedestrian evacuation to exit points beyond the hazard zone



MAP SHEET 5: Travel-time map of pedestrian evacuation to the assembly zone along Lake Ave.



MAP SHEET 6: Travel-time map of pedestrian evacuation to the assembly zone along Lake Ave and to two exit points on both sides of the lake. Exit points are marked by the bright green squares.